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Larry:

As I said over the phone we have found a positive correlation between voluntary dive time and size (of the turtle), the bigger the (turtle) the longer the dive. Dive (time) is probably due to the fact that while the lung volume increases in proportion to the body size, the specific metabolic rate (O_2 consumption/kg body weight) decreases.

More detailed study could probably come up with a relationship between exploitable depth (by the turtle) and body size that might be useful in assessing habitat value for sea turtles.

Peter

COPY J. H. OGREN
Turtles - TEDS

Forced and Voluntary Diving Response in the Sea turtle: Implications for Survival in Shrimp Trawls.

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Sea turtles are extremely capable divers known to survive for prolonged periods without access to air (Berkson, 1966; Lutz et al., 1970). It is somewhat paradoxical then that each year sea turtles are killed incidental to fishery operations such as shrimping or poundnetting (Ogren et al., 1977; Lutcavage and Musick, 1985). The assumption is that turtles either become asphyxiated or drown while held captive without access to air, yet these possibilities have not been verified by direct laboratory or field studies.

The following is a brief summary of research conducted on forced and voluntary diving in the loggerhead sea turtle, including results obtained from field sampling of Port Canaveral loggerheads. The results of these studies may be helpful in determining appropriate fishing guidelines that will reduce turtle mortalities associated with trawling or fishing activity.

I. Field studies - Blood chemistry profiles of loggerhead turtles trawled from the Cape Canaveral area showed seasonal variation in blood chemistry, including osmotic pressure sodium, and potassium (Lutz and Dunbar-Cooper, 1987). None of the reported blood chemistry values were significantly different from values obtained for captive animals. However, an interesting but unexplained trend of simultaneous seasonal changes in urea and osmotic pressure was reported. There is no evidence to suggest that seasonal variation in blood chemistry would have direct effects on dive endurance in wild sea turtles.

Hematocrit - Packed red blood cell volume (hematocrit) of Port Canaveral loggerhead turtles showed some slight seasonal variation, particularly in December 1979 values (5-15 vol %), which were less than half of baseline values (28-35 vol %). The reasons for the decline were not identified, and were not related to environmental factors. Low hematocrits are characteristic of sea turtles heavily infested with the marine leech Ozobranchus (personal observation), which often occurs in turtles bearing epithelial papillomas. Since oxygen used in respiration is carried bound to hemoglobin in red blood cells, it is possible that dive endurance may be shortened by a large reduction in hematocrit, seasonal or otherwise.

Lactate- In the laboratory, lactate values (baseline) for undisturbed loggerhead turtles are typically < 1 mMol. Immediately after capture, Port Canaveral loggerheads had mean on-deck lactate values of about 3-4 mMol, indicating trawl stress. Values obtained from turtles in a single trawl ranged as high as 8.8 - 16 mMol (Lutz and Dunbar-Cooper, 1987). Clearly, capture in fishing nets invokes a stress response in sea turtles, but whether high lactate values are attributed to anoxia or to struggling before capture cannot easily be resolved.

After 3 hr on deck, recovery blood samples show a 16.8% reduction in lactate, which in many turtles by 4 hr had fallen to

52% of post-trawl values. However, not all turtles recovered at that rate, since some turtles showed only a 16% decline in lactate after 5 hrs on deck. Lutz and Dunbar-Cooper state that the rate of decline of lactate was proportional to initial values. They further report that based on mean rate of decrease, the "least stressed" turtles would require 20 H for lactate values to return to baseline.

II. Laboratory Diving Studies- When a turtle dives, as oxygen is depleted from the lungs and blood, carbon dioxide increases and pH (acid-base status) falls, usually in proportion to the amount of time the turtle remains submerged (Lutz and Bentley, 1985). In laboratory studies I have found that after about 10 min of voluntary diving, the decline in pH is reversed through the buffering action of plasma bicarbonate ions [HCO_3^-]. A consequence is that CO_2 fails to accumulate beyond 40 Torr, and metabolic acidosis is prevented (Lutcavage, 1987). Furthermore, it appears that loggerheads surface to breathe before arterial pO_2 falls to 20 Torr. An example of this is provided in Fig. 1.

In loggerheads held at 25 ^{o}C, under voluntary diving conditions lactate values for arterial blood remain < 1 mMol. When the turtle emerges, following only a few breaths blood gas values for pH, pCO_2, pO_2 and [HCO_3^-] return to pre-dive values, and acid-base status is maintained. The turtle is then free to resume diving activity.

Physical characteristics also influence voluntary submergence time in sea turtles. Mean dive length in laboratory studies was directly related to body size (Fig. 2). There is

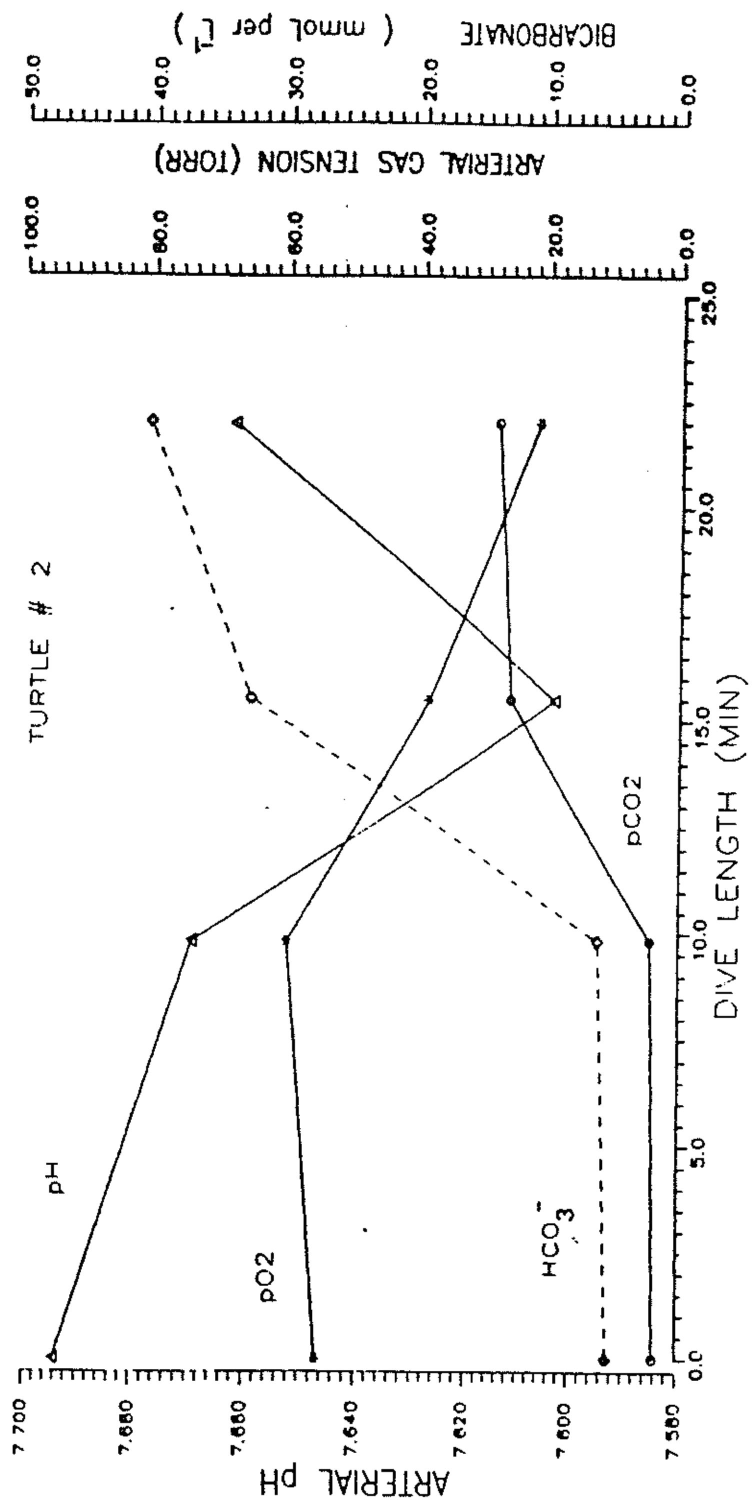

Figure 1. Arterial blood gas values obtained in Turtle #2 during a 22 min representative dive.

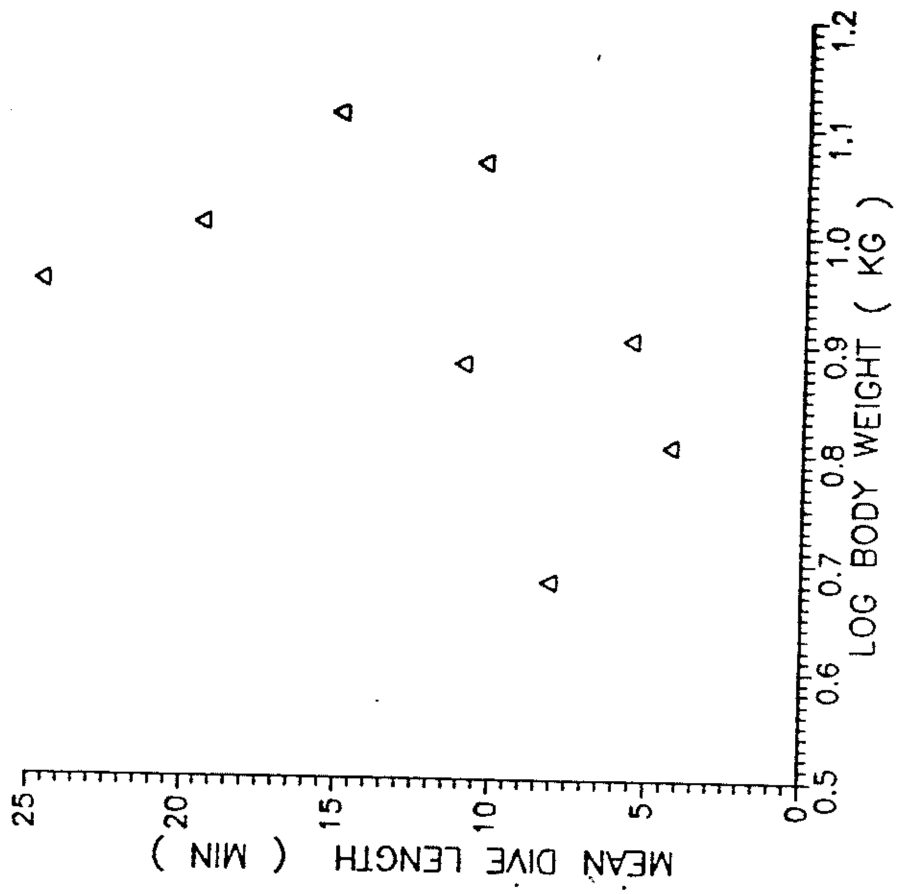

Figure 2. Relationship between turtle body weight and mean voluntary dive length (NVP).

also evidence that mean dive length decreases with increasing temperature. This means that smaller turtles in warm water would probably not survive as long without air as large turtles in cooler locations.

Forced Diving Studies- Blood gas properties were studied in loggerhead turtles that were forcibly submerged for 90 min periods (Bentley, 1981; Lutz and Bentley, 1985). Within 30 min of forced submersion blood gas stores of oxygen were entirely depleted (to 6 Torr), and reported venous CO_2 values were substantially higher than those reported for voluntary dives. After 90 min of submersion the mean venous blood lactate value was 17.8 mMol (almost 20x predive values), but plasma bicarbonate values remained low and turtles were acidotic.

When turtles were given access to air (30 min recovery period) pO_2 and pCO_2 returned to near predive values, but turtles remained acidotic. Lactate continued to increase (20.7 mMol), which indicates that lactate additional washout occurs from tissue stores when turtles resume breathing.

It can be estimated based on field data (Lutz and Dunbar - Cooper, 1987) that a 50 % reduction in lactate requires 4 H on deck. Lactate levels following a 90 min forced submergence would be about 10 mMol, which indicates the presence of a substantial O_2 debt even after 4 H of recovery.

Implications for Sea Turtle Survival in Trawls

It appears that under routine diving conditions sea turtles remain submerged until lung, blood and tissue stores of oxygen run out. Under normal circumstances blood gas values are held within aerobic limits, and the turtle remains free to make repetitive dives without prolonged ventilatory periods at the surface to overturn "oxygen debts". Activities that increase lactate levels, such as vigorous swimming or struggling, would decrease the amount of time a turtle could survive without air. It is also likely that features such as hematocrit, body fat stores, size, and environmental temperature would also affect survival in trawls.

In a report on sea turtle mortality in relation to shrimp trawl duration, Henwood and Stuntz (1986) reported that virtually no mortalities occured when turtles were captured in tows < 60 min. After that time limit, mortalities increased in proportion to the duration of trawling. An important question remains whether turtles that initially survive an hour shrimp haul would die in a much shorter period when recaptured if they were not held at the surface for a sufficient period of time. It seems likely that animals returned to the water with a lactate load (i.e. oxygen debt) would be much less capable of surviving subsequent tows.

Underwater observations confirmed that sea turtles vigorously attempt to outswim the shrimp trawl doors for up to 15 min (Terry Henwood, personal communication). In exercising sea turtles, Jackson and Prange (1979) have shown that metabolic rate increases up to 10 x resting values, and large quantitites of lactate are produced as by-products of muscular activity. It therefore seems reasonable to predict that animals that attempt to evade capture would have an additional O_2 deficit resulting from vigorous exercise. Consequently more time "on deck" would be required to replenish O_2 stores and eliminate lactate before the turtle can resume routine diving behavior.

It still remains whether turtles caught in trawls or set nets become asphyxiated or actually drown following aspiration of seawater. A strict definition of drowning requires the presence of water in the lungs. To my knowledge this has not been reported in sea turtles. In humans, survival chances are higher if drowning occurs in cold water, which is believed to enhance the "diving reflex". Survival chances are also improved in seawater or highly chlorinated water, because cellular osmotic pressure and volume changes are not as drastic as those that occur following drowning in fresh water. It seems reasonable to speculate that in some cases sea turtles may survive aspiration of seawater, but it is imposssible to predict conditions that would enhance recovery without appropriate laboratory and field testing.

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